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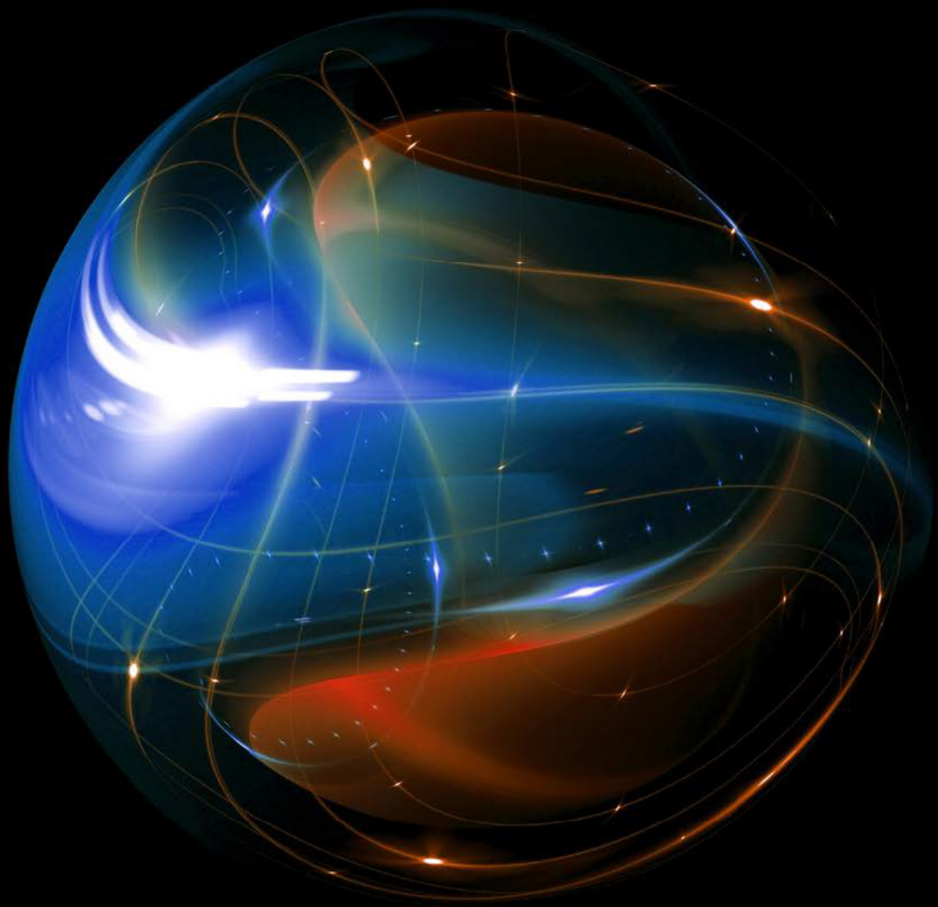


The imperative for carbon management

Contents

Combating the climate challenge

As the urgency of climate action intensifies, a larger, more complex portfolio of strategies seems to be coming into focus. Scientific assessments in recent years have shown that, while we likely need massive efforts to decarbonize our economy, we cannot rely on mitigation alone to stabilize the climate. In addition to rapid deployment of renewables, energy storage, and electric vehicles, we should also change how carbon is managed across its entire cycle—from fossil fuel extraction and combustion; to the natural sequestration and release of carbon through forests, soils, and oceans; to engineered solutions that enable carbon capture from the atmosphere or from a source for utilization, temporary storage, and/or permanent removal. However, these carbon management actions are often pursued in isolation, without a coherent picture of how carbon moves through natural and industrial processes. Instead, a system-based understanding of *carbon management*[1] can help us think more clearly about the broader landscape of emissions reduction solutions given the scale and speed of the climate challenge.

Several challenges have prevented carbon management technologies (including carbon capture, utilization, and storage [CCUS] and carbon dioxide removal [CDR]) from being deployed more rapidly in the United States, but a growing number of companies and startups are developing innovative business models that can circumvent these challenges and scale these technologies. Several factors could expedite the development of the carbon management ecosystem including increased clarity on carbon value, managing risk across complex and cross-border value chains, standardizing reporting mechanisms at a federal level, and reducing regulatory uncertainty. But even in their absence, the urgency to slow climate change has attracted new businesses and investment into the carbon management ecosystem over the past four years, with carbon capture capacity under development increasing fivefold.[2] Many companies are adopting innovative business models that leverage partnerships, lower the costs of CCUS and CDR technologies, and increase the value and visibility of future revenue streams. As these companies deploy their technologies, costs should decline, momentum will likely build, and eventually, every company that makes or uses carbon-based fuels or products could become part of an emerging carbon management ecosystem.

IPCC mitigation strategies

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations' body tasked with assessing the science related to human-induced climate change. In its Sixth Assessment Report released in April 2022, the IPCC stated that all modeled pathways that limit global warming to 1.5°C or 2°C above pre-industrial levels will require swift and sizable GHG emissions reductions across sectors.[3]

Proposed mitigation strategies to achieve these reductions include (1) transitioning from fossil fuels without carbon capture and sequestration (CCS) to low- or zero-carbon energy sources such as renewables or fossil fuels with CCS, (2) increasing demand-side measures and energy-efficiency measures, and (3) deploying CDR methods. While CDR is necessary in all pathways that limit warming to 1.5°C, the amount of CDR necessary varies widely on the order of 100–1,000 gigatons of carbon dioxide (CO2), depending on assumptions about near-term emissions abatement, cost, availability, and technological constraints.[4] The IPCC also points out that current global rates of CCS deployment are significantly below those modeled in pathways, and changes in policy, public support, and technological innovation will be necessary to increase deployment.[5]

Infographic

The carbon management ecosystem

Building industries that mitigate climate change

Point source carbon capture and storage (CCS) has been around since the 1970s, but the technology has not yet commercialized and scaled. A renewed urgency to reach net zero emissions targets has presented new growth opportunities for the industry. And it's just one component of the developing carbon management ecosystem, which has the potential to become an integral part of a more climate-friendly economy. Discover the scale of the issue, the potential of a carbon management solution, and where a range of industry players can enter the ecosystem.

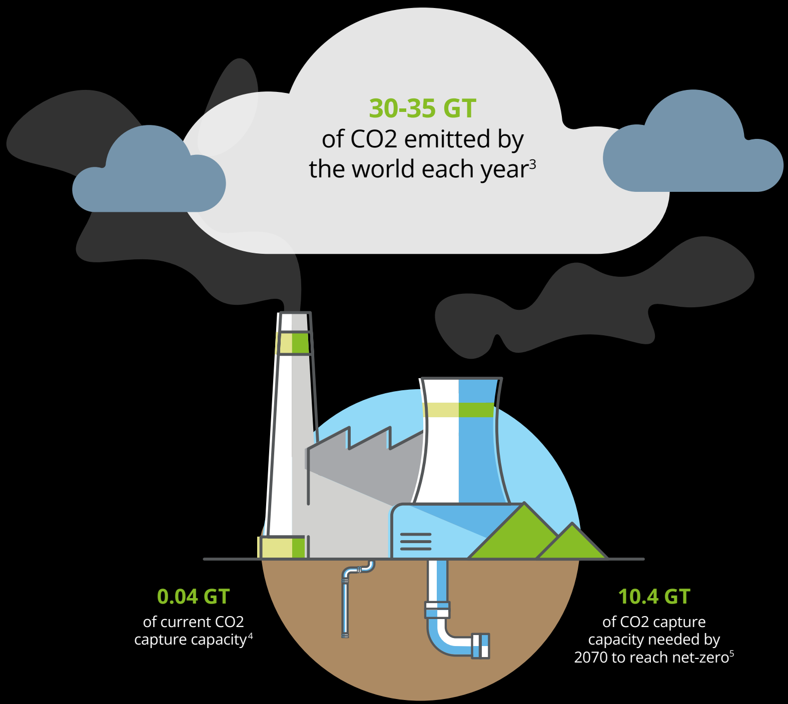
Why now?

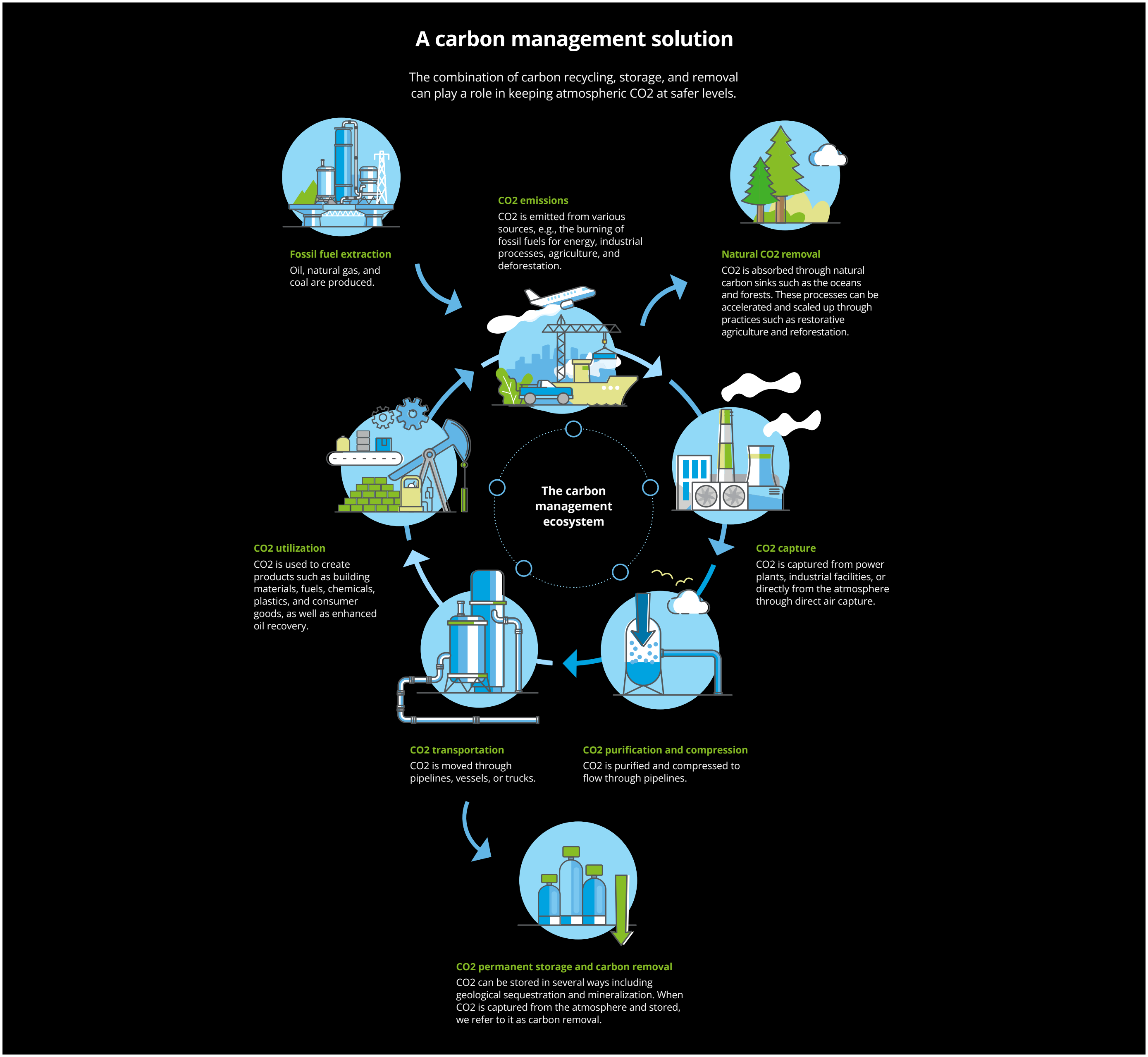
CO2 accounts for approximately 75% of global greenhouse gas (GHG) emissions.[1]

Limiting global warming to 1.5 degrees Celsius above pre-industrial levels will require GHG emissions to peak before 2025 and be reduced by 43% by 2030.[2]

Scaling up carbon management could help meet this climate goal.

The size of the challenge

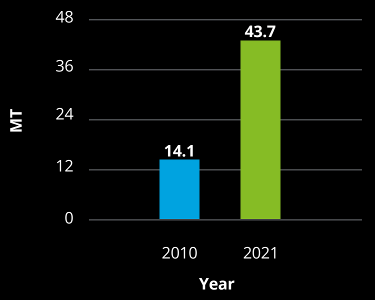



A carbon management solution
The combination of carbon recycling, storage, and removal can play a role in keeping atmospheric CO2 at safer levels.
Fossil fuel extraction
Oil, natural gas, and coal are produced.
CO2 emissions
CO2 is emitted from various sources, e.g., the burning of fossil fuels for energy, industrial processes, agriculture, and deforestation.
Natural CO2 removal
CO2 is absorbed through natural carbon sinks such as the oceans and forests. These processes can be accelerated and scaled up through practices such as restorative agriculture and reforestation.
The carbon management ecosystem
CO2 utilization
CO2 is used to create products such as building materials, fuels, chemicals, plastics, and consumer goods, as well as enhanced oil recovery.
CO2 capture
CO2 is captured from power plants, industrial facilities, or directly from the atmosphere through direct air capture.
CO2 transportation
CO2 is moved through pipelines, vessels, or trucks.
CO2 purification and compression
CO2 is purified and compressed to flow through pipelines.
CO2 permanent storage and carbon removal
CO2 can be stored in several ways including geological sequestration and mineralization. When CO2 is captured from the atmosphere and stored, we refer to it as carbon removal.

Building momentum

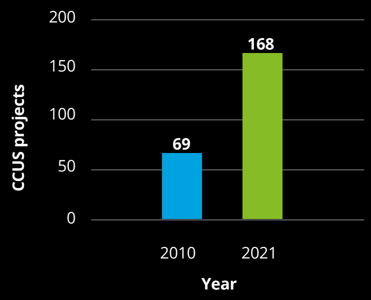
More carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) projects are being deployed.

CO2 capture capacity



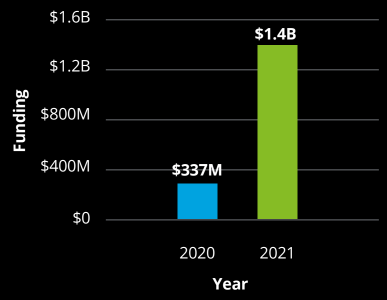
Operational carbon capture capacity has increased **3X** since 2010.[6]

Projects under development or announced



The number of projects under development or announced has increased more than **2X** since 2010.[7]

Venture capital funding into CCUS startups



Venture capital funding into CCUS startups rose **4X** between 2020 and 2021.[8]

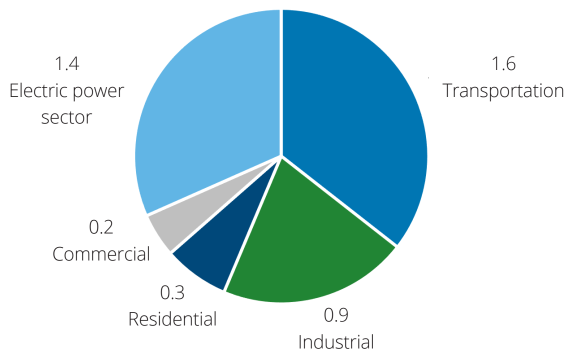
1. Blanco G., R. Gerlagh, S. Suh, J. Barrett, H.C. de Coninck, C.F. Diaz Morejon, R. Mathur, N. Nakicenovic, A. Ofosu Ahenkora, J. Pan, H. Pathak, J. Rice, R. Richels, S.J. Smith, D.I. Stern, F.L. Toth, and P. Zhou, 2014: Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 354.
2. IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 21.
3. IEA (2020), CCUS in Clean Energy Transitions, IEA, Paris.
4. Ibid.
5. Ibid.
6. IEA (2021), Carbon capture in 2021: Off and running or another false start?, IEA, Paris.
7. Ibid.
8. CB Insights, "Carbon Capture, Utilization, and Storage (CCUS) Expert Collection," accessed January 31, 2022.

Key components of the carbon management ecosystem

Carbon capture

In this paper, carbon capture refers broadly to any engineered process of capturing carbon from a source of emission or directly from the atmosphere. Point source carbon capture refers specifically to capturing carbon at the point at which it is emitted to the atmosphere. More than half of all CO2 emissions in the United States come from electricity generation and industry.[6] Point source carbon capture and sequestration (CCS) can play an important role in these sectors, particularly in hard-to-abate industries. In the United States, today, most operational point source capture is located at natural gas processing, ethanol, or fertilizer facilities. However, proposed projects have become diverse with applications at power, hydrogen, and cement plants rising.[7] In contrast, direct air capture (DAC) is a technology that captures carbon directly from the atmosphere.

Figure 1. US CO2 emissions by sector in 2020 (billion metric tons)



Source: US Energy Information Administration, *Monthly Energy Review*, April 2022, Tables 11.1-11.6

Purification/transportation

CO2 can be transported as a gas, liquid, or solid, but most commercial-scale transport will be as compressed gas through a pipeline or liquefied gas on a ship. Pipelines are currently the most common method of transporting CO2, with nearly 5,000 miles of CO2 pipelines currently in the United States. (Note that this is far less than the nearly 3 million miles of natural gas pipelines.[8]) Pipelines have specifications for composition. Depending on the source of CO2, the stream may need to be purified before transporting. For instance, water, hydrogen sulfide, sulfur, and nitrogen may need to be removed.[9]

Utilization

Once captured from the environment, CO2 is either utilized or stored. The term *utilization* refers to the incorporation or transformation of captured CO2 into a product or service that generates economic value. Due to current economic drivers, the most common form of utilization in the market today is use of captured and pressurized CO2 for enhanced oil recovery (EOR)—in fact, today, 13 out of the 14 commercial CCS facilities in the United States utilize EOR.[10]

Storage

Once carbon has been captured—whether from the atmosphere or point source—it can be stored. Storage is often evaluated on its durability. Here, durability refers to both the permanence of the storage and its risk of reversal (or leakage). The permanent storage of carbon could be critical to meet IPCC targets. The most mature permanent storage technology is geological sequestration in deep saline aquifers. CO2 can also be stored in underground formations such as oil and natural gas reservoirs, un-mineable coal seams, basalt formations, or organic-rich shales.[11] Additionally, CO2 storage via enhanced weathering/mineralization and ocean alkalinization is in early development.

Carbon dioxide removal

Carbon dioxide removal (CDR) refers to human activities that remove and durably store CO2 from the atmosphere.[12] CDR approaches broadly include nature-based solutions (e.g., reforestation, ocean alkalinity), technology-based solutions (e.g., direct air capture to storage, mineralization), and a mix of nature- and technology-based solutions (e.g., biochar). It is important to note that durable storage or permanent removal of carbon from the atmosphere is required for classification of a technology approach as CDR. Many utilization technologies would not qualify as they do not involve permanent removal of carbon.

It is unlikely that any one CDR approach will have large enough potential to remove all the CO2 required to meet the IPCC target. But many emerging CDR approaches have the potential to play a significant role in meeting the target together. The Rhodium Group has estimated that US demand for direct air capture (DAC), a technology that pulls carbon directly from ambient air, could reach $259 billion by 2050.[13] Though to achieve carbon removal, that CO2 would need to be stored permanently after it was captured.

Finance

Various CCUS and CDR technologies are at different levels of readiness, which is reflected in their funding sources and levels. Public or government funding, corporate funding, and venture capital funding tend to be the most prevalent.

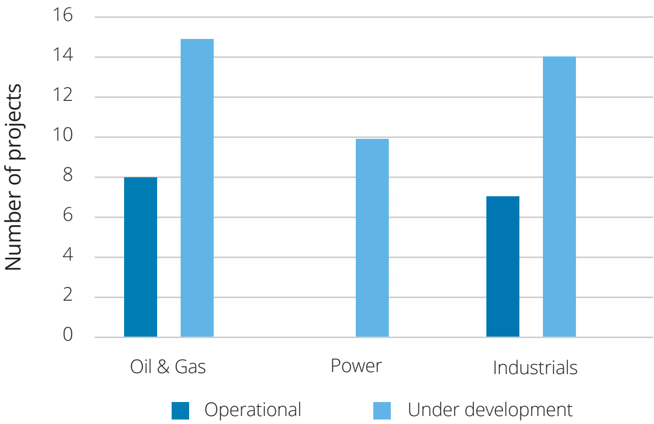
Public and government funding critical in early stages: In the research and development stages, the federal government, universities, and research institutes continue to play a critical role in financing development. Federal and state funding and tax credits can help accelerate adoption by making the technologies more economic. For example, the 45Q tax credit[14] in the United States provides incentive per metric ton of carbon captured, sequestered, or utilized.[15] The Infrastructure Investment and Jobs Act will allocate approximately $6.5 billion in funding for CCUS and CDR technologies over five years, with an additional $5.6 billion allocated to CCUS and CDR technologies through the Office of Clean Energy Demonstrations (OCED) and Department of Energy (DOE) Loan Programs Office.[16] In Canada, the Federal Budget 2022 included plans for climate-related financial disclosures and financial incentives through the CCUS investment tax credit.[17]

Corporate funding can help speed commercialization: More recently, corporations have begun to enter the space, purchasing carbon removal credits to meet their net-zero goals. While standardized methodologies and accounting standards for carbon removal credits are not yet widely available (but under development), some corporate supporters have pioneered this investment approach to help expedite CDR technology development, deployment, and scaling up required to bring down cost. Accelerators are also driving innovation by providing funding and facilitating partnerships through contests and network building. However, as technologies reach deployment, partnerships can form, and more companies begin to adopt the technology.

Venture capital funding is ramping up for research and development as well as commercialization: Between 2020 and 2021, the number of projects more than doubled, and the total venture capital funding more than quadrupled.[18] Much of this investment supported utilization use cases and emissions tracking and management software.

While the funding sources and partnerships of each project are not always transparent, Deloitte analyzed 39 commercial CCS projects in operation or under development in the United States.[19] Of the project analyzed, oil and gas companies are involved in at least 80% of the operational CCS projects and more than 60% of the projects under development. Industrial companies are involved in at least 70% of the analyzed projects in operation and at least 50% of those analyzed projects under development. Meanwhile, power generators have increased their involvement to participate in at least 40% of analyzed new projects under development.[20]

Figure 2. Partnerships in sampled commercial CCS projects by industry



Note: Several projects have partners in more than one category (oil & gas, power, industrials).

Sources: Turan et al., *Global status of CCS 2021*, Global CCS Institute, October 2021, pp. 62-6; Deloitte analysis.

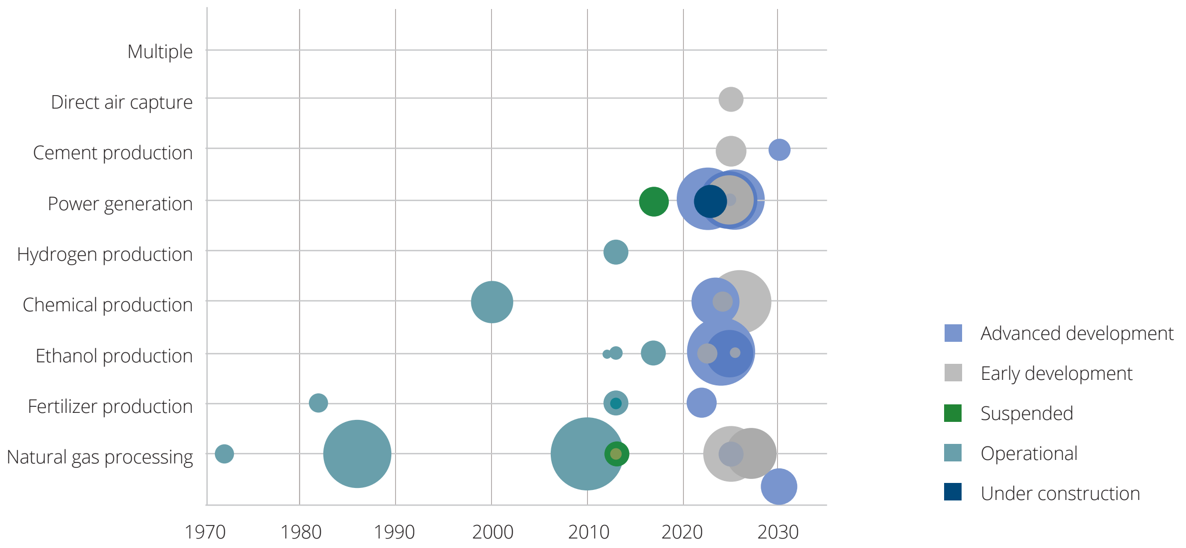
Current state of the ecosystem

Wider adoption of emissions targets and more favorable government policies have driven investment into CCUS and CDR in recent years, with the number and diversity of players growing significantly. When CCS began being adopted in the 1970s, oil and gas companies were at the forefront, capturing CO2 from natural gas processing plants for use in EOR.[21] By 2014, the first large-scale coal-fired power plant with CCS began in Canada.[22] In the United States, there are now more than 70 projects in the early to advanced development stages that span seven different industries, from ethanol production to power generation to direct air capture.[23]

Despite this momentum, CCUS and CDR will need to scale much more quickly to meet the IPCC's 1.5°C target, but major challenges persist.

1. **Cost:** The high costs associated with CCUS technologies are often cited as one of the key reasons that deployment has not occurred faster.[24] However, there is a large range of costs for CCUS technologies, depending on factors such as the source of the CO2 captured, the volume of CO2 captured, the distance it must be transported, and how it is used or stored.[25] As technologies mature and economies of scale are

Figure 3. Operational and planned commercial CCS facilities in the United States



Source: Adapted from Turan et al., *Global status of CCS 2021*, Global CCS Institute, October 2021, pp. 62-6.

realized, costs will likely come down. For instance, the cost of carbon capture at power plants fell 35% from the first to the second large-scale facility built.[26]

2. **Lack of federal carbon pricing mechanism:** While tax credits, regional compliance markets, and voluntary carbon markets exist in the United States, there is currently no federally mandated mechanism for assigning a value to carbon. For example, a carbon price could provide companies with incentive to reduce emissions and give clearer value to CCUS and CDR technologies. This could be done through a carbon tax (like in Canada) or through a "cap-and-trade" system (like the EU Emissions Trading System). Policies like 45Q and California's Low Carbon Fuel Standard (LCFS)[27] offer some ways to assign value to CO2. But the values through 45Q are still relatively low considering the cost and urgency of carbon management technologies, and not all CCUS projects qualify for the LCFS.

3. **Complexity:** Apart from a few vertically integrated oil and gas companies that have experience and existing infrastructure in CCS, most other companies only operate in one part of the value chain and seek partnerships with other companies to provide services like transport and storage. Risks arise from working with several partners across the value chain that have different budgets, timelines, ambitions, and risk tolerances.

4. **Lack of federal standards:** While there are a number of well-recognized and widely used carbon-offset accounting standards, there are currently no federally adopted standards in the United States for carbon offsets or carbon removal credits. Monitoring and reporting should be mandatory, comprehensive, auditable, and based on agreed-upon standards to provide consistency and transparency across reports. Offset calculations, specifically, can become extremely complex when considering factors such as durability and additionality. They become even more complicated when companies are making decisions or investments in different countries that lack alignment across different jurisdictions.

5. **Regulatory uncertainty:** Regulation currently lags commercial development within the carbon management ecosystem. More specifically, the regulations governing long-term liability of geological storage, well permitting, and pipeline classification should all be clarified and streamlined at the state and federal levels.

Several measures could be taken related to these challenges to facilitate growth in the ecosystem. Creating a compliance market for carbon removals (or incorporating carbon removal requirements in existing carbon compliance markets) would increase the value of CO2 removed from such investments. A compliance market would also add transparency and verifiability to the carbon market and could increase the stability of carbon pricing, making long-term investment decisions less risky. Several large corporations have shown interest in purchasing carbon credits to offset their emissions, but very few carbon capture/removal projects exist to serve this demand. Creating a value of CO2 that is transparent into the future could help accelerate the number of financial investment decisions (FIDs) reached. On the regulation side, the Securities and Exchange Commission (SEC) recently proposed a rule that would require companies to disclose their emissions to investors.[28] This could be a step toward establishing standardized accounting for CO2 emissions and offsets.

SEC proposed rules to enhance and standardize climate-related disclosures

In March 2022, the Securities and Exchange Commission (SEC) proposed new disclosure rules that would require registrants to disclose annually climate-related information. Registrants would be required to disclose:

- Climate-related risks and their actual or likely material impact on the company's business model, strategy, and outlook;
- Governance of climate-related risks and relevant risk management processes;
- The registrant's greenhouse gas (GHG) emissions;
- Certain climate-related financial statement metrics and the impact of climate-related physical events and transition activities on estimates and assumptions; and
- Information about climate-related targets and goals, and transition plans, if any.[29]

The disclosure of GHG emissions includes Scope 1 emissions (direct emissions from sources owned or controlled by the registrant) and Scope 2 emissions (indirect GHG emissions from purchased electricity and other forms of energy) separately disclosed on a disaggregated (by constituent gases) and aggregated basis. The disclosure would be required on a gross basis (before offsets) and relative intensity (e.g., tons of CO2 per dollar of revenue). Scope 3 emissions (emissions from indirect upstream or downstream activities in a registrant's value chain) would also be required to be disclosed on a gross basis and in terms of relative intensity if (1) those emissions are material or (2) if the registrant has set a GHG emission reduction target that includes its Scope 3 emissions. These GHG emission disclosures would be subject to additional attestation requirements.[30]

Disclosure requirements would be phased in over several years, depending on the size of the registrant and the specific disclosures. Yet if rules are finalized and effective starting December 2022, disclosures could be included in certain 2023 annual reports.[31]

Emerging business models

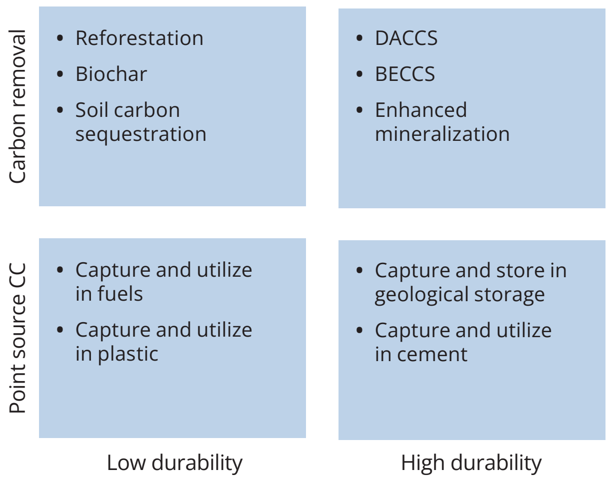
For CCUS and CDR technologies to scale to meet IPCC targets, many businesses are creating models that circumvent the challenges and help position the company for success once regulations are established. Here, business model is defined as the way a company seeks to solve a problem and how it can do so profitably. While there are many components of a successful business model, we examine four here: (1) value proposition (assumed here to be a reduction in CO2 emissions), (2) partnerships, (3) revenue streams, and (4) cost structures.

Value proposition: Impact on emissions

A company's value proposition will be specific to each company, but they should all have in common a goal to reduce and/or remove CO2 emissions. There are five main factors to assess when evaluating a project's impact on emissions:

1. **The source of the CO2.** For a project to qualify as CDR, it must remove CO2 from the atmosphere, achieving negative emissions.[32] If the CO2 is captured from a power plant and permanently stored, it is likely to be considered an emissions reduction rather than negative emissions.
2. **The duration of the storage.** Different uses of or methods of sequestering/removing CO2 have different life spans—carbon mineralization in basalt formations could be considered as permanent removal; EOR and cement curing may store CO2 for centuries or more, while urea and fuels may only store CO2 for a few days or months.[33]
3. **The risk of storage reversal.** Reforestation is considered long-term storage; however, the possibility that there could be a forest fire makes this form of storage riskier relative to geological storage or mineralization.
4. **The source of any energy consumed.** To ensure and maximize a net emissions reduction, the energy used for any CCUS or CDR project should be minimized or sourced from clean energy fuels whenever possible. For instance, polymer processing with CO2 requires relatively less energy input than conversion of CO2 to fuels or chemical intermediates. The latter cases would benefit from the use of clean energy sources.[34]
5. **The impact on emissions of alternatives.** As mentioned, most point source carbon capture is currently used in EOR to make the project more economical. However, some critics argue that using carbon capture in EOR increases CO2 emissions because it produces more fossil fuels that will be burned downstream, releasing more CO2 (the rebound effect).

Figure 4. Examples of technologies and their emissions durability



Source: Deloitte and Duke analysis.

Partnerships

Today, projects are usually contractually organized in one of three ways: (1) vertical integration, (2) joint ventures (JVs), or (3) collaboration with a service company.

Vertical integration has been adopted by some oil and gas companies with experience in capturing, transporting, and storing or utilizing CO2. These companies can reduce supplier risk, lower costs, and benefit from economies of scale by vertically integrating.

Joint ventures are a popular structure for many of the existing CCS projects. Many power generators have set up JVs rather than develop new core competencies and incur additional capital costs. Instead, they are working with partners that already have experience in CCUS. In doing so, they share the costs, risks, and liabilities. The company they partner with benefits from expanding their footprint, experience, and economies of scale.

Collaboration with a service provider is becoming more common. Services are beginning to be offered by companies with experience along the CO2 value chain. Service providers gain experience and economies of scale, while the buyer of the service reduces their investment costs and overall risks (e.g., operational risks, cost overrun risks), while increasing their service cost and third-party risk.

Revenue streams

Most revenue streams for CCUS and CDR projects fall into one of four categories: (1) tax credits or other government incentives, (2) sale of carbon credits into voluntary carbon market, (3) sale of CO2 for added value, or (4) sale of services.

Tax credits: Many companies that capture and sequester CO2 will be able to receive the 45Q tax credit. In addition, some ethanol companies are capturing and sequestering CO2 underground to generate credits under California's Low Carbon Fuel Standard.[35]

Voluntary carbon market: Demand for carbon removal in the voluntary carbon offset market is driven by climate-oriented corporate buyers with net-zero emissions commitments. Carbon removal is generally productized and sold to corporate buyers either on a subscription basis or as part of a long-term contract for receiving rights to claim carbon removal credits as offsets against their net-zero and carbon-neutral commitments. Some corporate buyers are also investors, taking an equity stake in a carbon removal project or company. A handful of large, mostly tech-based companies are investing millions of dollars to purchase carbon removal offsets at prices ranging from $75–$2,000/ton CO2. Their intention is to catalyze the fledgling carbon removal offset market and bring down the price of novel technologies.[36] For comparison, the DOE has announced a target price point of $100/ton of CO2 equivalent for CDR technologies as part of its "Energy Earthshots" Initiative.[37]

CO2 utilization: Global demand for CO2 has traditionally been concentrated in the production of urea for fertilizer (57%) and EOR (34%).[38] In both applications, the capture and use of CO2 are performed by the same company, and capturing the CO2 replaces additional CO2 that would otherwise be purchased. A growing number of startups are using CO2 to produce building materials, chemicals, fuels, and other consumer goods to build demand for captured CO2 and thus create more value for it. Many of these technologies are still in early development, but some have become commercial. As the carbon management ecosystem develops, other potential use cases may become more economically viable, including the production of plastics, chemicals, fuels, or other novel consumer products. Several organizations have estimated the global market for CO2 utilization could reach between $70 billion and $1.1 trillion by 2030.[39]

Sale of services: As mentioned, more companies are offering services within the carbon management ecosystem that include capturing, transporting, storing, or using CO2. For instance, one industrial biotech startup works with companies in hard-to-abate industries to find ways to utilize their captured CO2 onsite using synthetic biology to create products such as ethylene used in plastics.

CDR gaining momentum

Over the past three years, several corporations ranging from technology companies to airlines have invested in carbon removal.[40] Stripe, Microsoft, and Shopify have not only made CDR a focus but also have been transparent with their approaches, criteria, and investments. Stripe and Shopify have already supported 10 and 22 startups with $15 million and $32 million, respectively.[41] These agreements have helped startups secure venture capital funding for a variety of applications such as direct air capture, bioenergy with carbon capture and storage, forestation, sequestering CO2 in concrete, and using CO2 in the production of chemicals and fuels. Companies hope that by investing in these startups, deployment will accelerate.

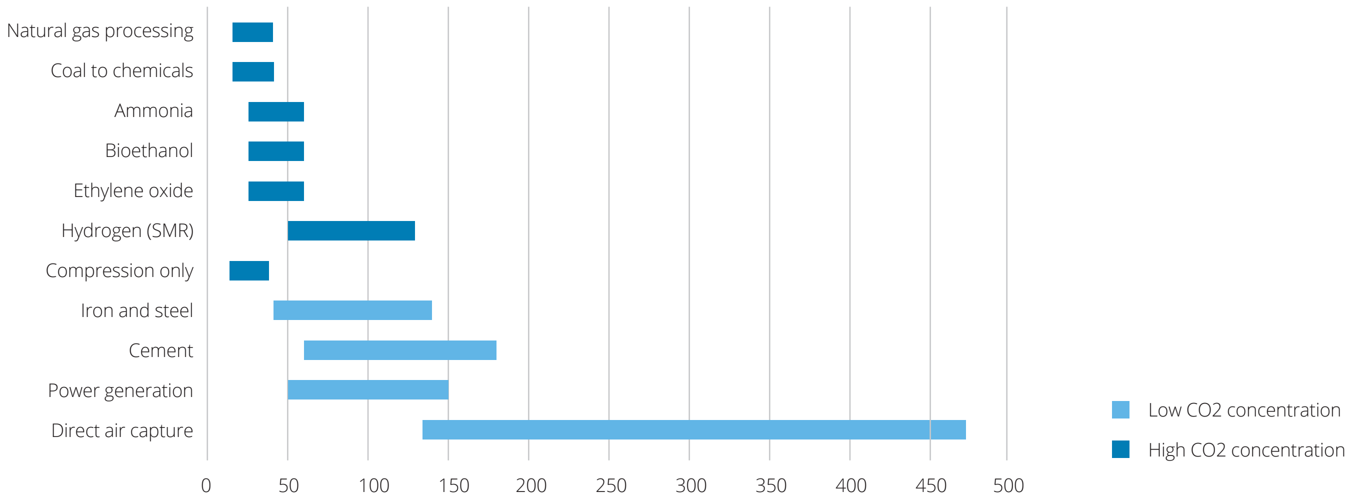
Cost structures

For carbon capture, costs depend on: (1) CO2 concentration in the source gas stream, (2) contamination or impurities in the gas stream, and (3) the source mass flow rate,[42] and (4) the modularity of the unit. The latter two variables allow for benefits from economies of scale. High concentrations of CO2 in the gas stream and a faster mass flow rate translate to higher volumes of CO2 captured over the same amount of time. Fewer impurities in the gas stream require less purification. The modularity of the unit also helps reduce cost by reducing the costs associated with individual product configurations.

There are many different types of CO2 emitters located all over the United States, not always close to an area of CO2 demand or storage. The costs associated with tailoring carbon capture equipment to each type of emitter or building out the pipelines required to move CO2 across the country are too high for scale to be achieved quickly. But there are numerous companies and organizations developing innovative solutions to solve these scalability issues. For example, one company is working on modular carbon capture equipment that could "plug-and-play" into many different types of CO2 sources, like chemicals plants, coal-fired generators, and ethanol plants. Other companies have adopted a hub or cluster model, where carbon is captured from multiple sources in proximity and then transported to a hub where the CO2 is stored or utilized.

Like point source carbon capture, CDR businesses can only scale if they overcome challenges such as the small scale of CO2 transport capacity in the United States. Of the nearly 5,000 miles of CO2 pipelines in the United States, more than half are located in the Permian Basin. Additional CO2 pipelines run through the Gulf Coast, Rocky Mountains, Mid-Continent, Michigan, and North Dakota.[43] To address this challenge, some providers have centralized

Figure 5. Levelized cost of capture (USD/ton) and CO2 concentration by source



Source: Adam Baylin-Stern and Niels Berghout, "*Is carbon capture too expensive?*," IEA, February 17, 2021.

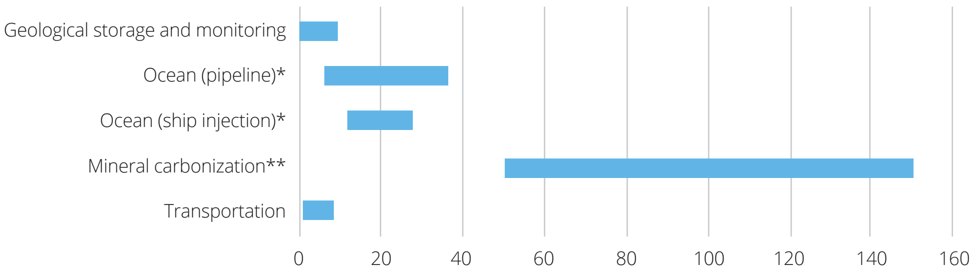
operations and collocated near the captured carbon's end use (e.g., a large DAC facility located near geological storage or enhanced oil recovery operations). For example, some carbon removal companies have partnered with oil and gas companies that already have experience in EOR or EPA-approved geological storage.

Decentralized business models utilizing dispersed resources or infrastructure have also emerged. Examples of this approach include modifying existing HVAC equipment on buildings for DAC or generating durable bio-based products from organic waste on various sites and transporting it for permanent storage. In many of these decentralized cases, carbon removal companies have outsourced aspects of the value chain to other companies.

For many nature-based CDR solutions, the business models are distinct from the centralized and decentralized models described above. In some instances, like nature conservation and regenerative soil practices, a company offers landowners or farmers compensation for afforestation/reforestation or adopting new planting/soil practices. The company then bundles and sells the carbon credits that are generated from those practices. In other instances, for technologies such as biomass, a company will grow the crops or partner with a nearby farmer. The biomass is then converted into a product or injected into long-term storage. The scalability of each of these businesses is restricted in part by land use, and some biomass may compete with land use for food or other crops. Scalability is further challenged by the inherent tension between buyers that want greater durability and landowners that may not be able to tie up their land use in long-term contracts.

Geological sequestration of CO2 is regulated by the EPA and permitting these facilities is neither fast nor cheap. As a result, ownership of most of the geological storage in the United States is dominated by oil and gas companies. These companies have vertically integrated to use the geological storage for their own needs and partnered with nearby emitters to offtake the CO2 and permanently store it. Several companies are beginning to offer transport and storage services. Nearly all these projects are built around the hub model to scale and remain profitable. One academic-industrial partnership is working on a demonstration project to use mineralization to permanently store point source carbon. If successful, the technology could solve some of the geographical constraints that geological storage faces.

Figure 6. Estimated cost of CO2 storage and transport (USD/ton by type)



*Includes offshore transportation costs; range represents 100–500 km distance offshore and 3000 m depth.
**Unlike geological and ocean storage, mineral carbonization requires significant energy inputs.

Source: Bert Metz, IPCC special report on Carbon dioxide capture and storage, IPCC (UK: Cambridge University Press, 2005).

Building industries that mitigate climate change

The development of a carbon management ecosystem is a vital part of tackling the climate crisis with speed. As technologies mature, prices drop, and the value of CO_2 increases, the pace and scale of growth in this ecosystem is expected to accelerate. Once scaled, the ecosystem could touch all parts of the economy, capturing carbon from emitters and ambient air; transporting carbon to plants for conversion into building materials, fuels, and chemicals; or to different permanent storage options. Nature-based solutions can leverage farms, forests, and oceans to remove carbon. Challenges still exist, especially with regards to markets and regulation, but companies are working together to develop innovative business models to overcome these challenges. Investment in the ecosystem has hit record highs, more players are entering the space, and those companies that are able to develop successful business models could lead the market.

Let's talk

Kate Hardin
Executive Director
Deloitte Research Center for Energy & Industrials
Deloitte Services LP
khardin@deloitte.com

Nichelle McLemore
Managing Director
Oil, Gas & Chemicals
Deloitte Services LP
nichellemclemore@deloitte.com

Daniel Vermeer, Ph.D.
Associate Professor of the Practice of Energy & Environment and Executive Director,
Center for Energy, Development and the Global Environment (EDGE)
Fuqua School of Business, Duke University
daniel.vermeer@duke.edu

Authors

Ashlee Christian
Manager
Deloitte Research Center for Energy & Industrials
Deloitte Services LP

Kacey Katzenmeyer
Master of Environmental Management (MEM) Candidate
Nicholas School of the Environment
Duke University

Key contributors

Adam Samazin, consultant, Energy, Resources & Industrials, Deloitte Consulting LLP
Jay Shannon, specialist leader, Energy, Resources & Industrials, Deloitte Consulting LLP

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